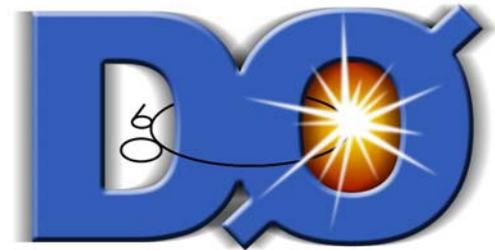


Top Quark Mass Measurements at the TeVatron



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University of Rochester



for the CDF and DØ collaborations

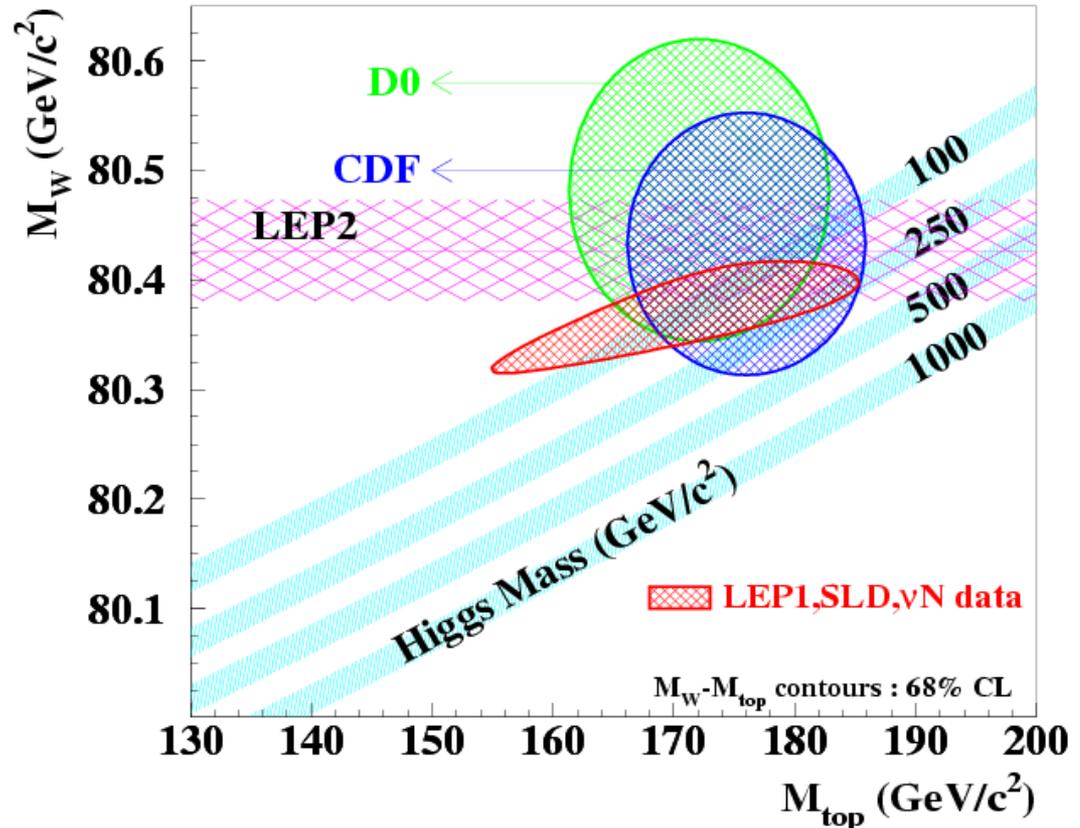
Two new (preliminary) results:

- CDF Run II ($\sqrt{s} = 1.96\text{TeV}$, 2001 - present)
- DØ Run I ($\sqrt{s} = 1.8\text{TeV}$, 1992 - 1996)

Top Quark Mass

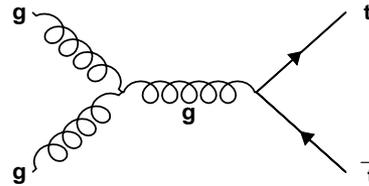
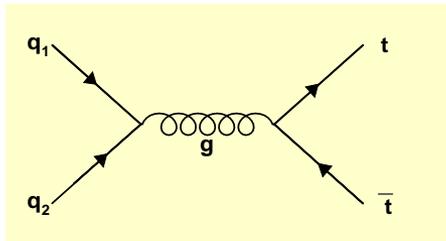
- The top quark mass, M_{top} , enters as a parameter in the calculation of radiative corrections to other Standard Model observables

- M_{top} can be related, with m_W , to the **Higgs mass**
- M_{top} is roughly $\frac{1}{2}$ the **vacuum expectation value** of the Higgs field
- better understanding of **EWSB** mechanism?
- to perform more precise tests we need:
 - more data**
 - and**
 - improved techniques**



Top Quark Production and Decay

In proton antiproton collisions at TeVatron energies, top quarks are primarily **produced in pairs**



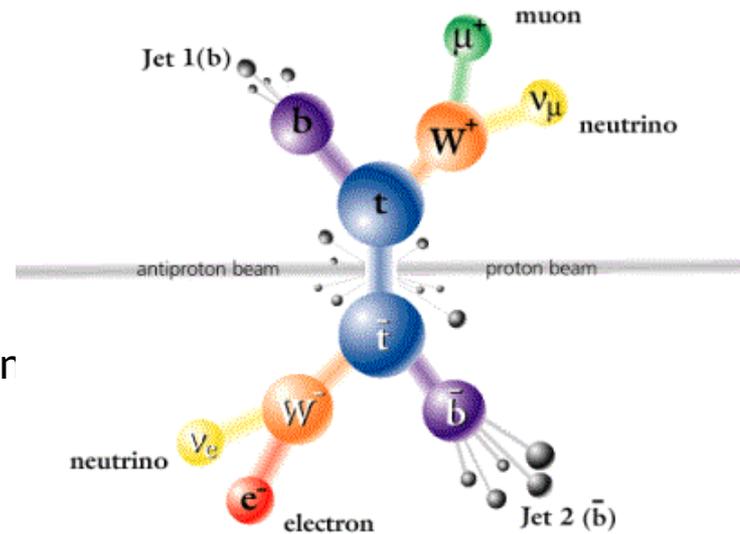
Single production via weak interaction: **not yet observed**

Each quark decays ~ 100% into a W-boson and a b-quark

BR($t \Rightarrow Wb$) @ 100%

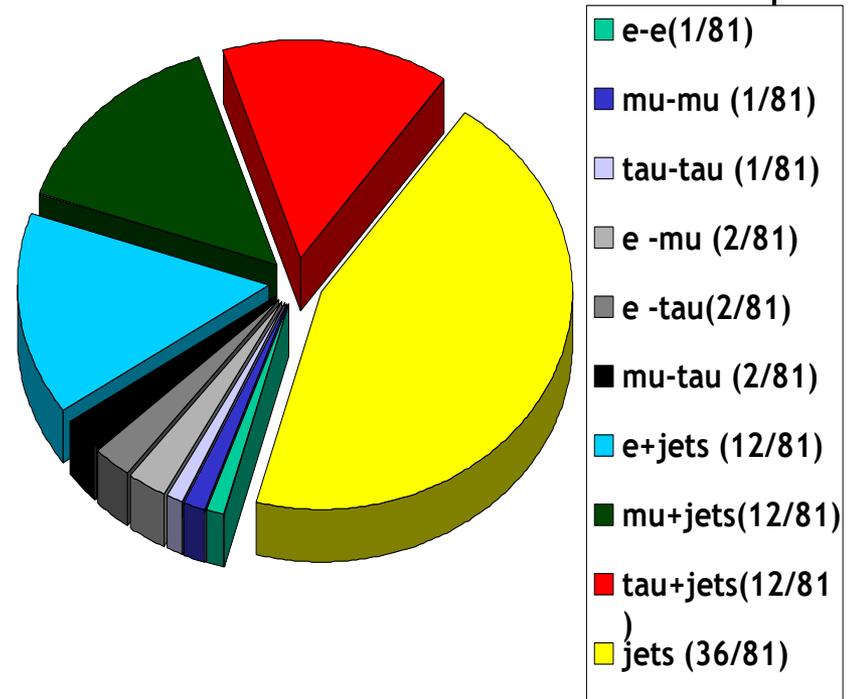
3 main experimental signatures depending on the decay of the W boson:

dilepton, lepton+jets, all-hadronic



ttbar Decay Signatures

- DILEPTON BR($ee+\mu\mu+e\mu$) = 5%
 - Small background
 - Small cross section
 - 2 high- p_T leptons, 2 b jets, large missing- E_T
- LEPTON +JETS BR($e+jets,\mu+jets$) = 30%
 - manageable backgrounds
 - higher statistics
 - 24 jet combinatorics
 - 1 high- P_T lepton, 4 jets (2 b jets), large missing- E_T
- ALL-HADRONIC BR(jets)=44%
 - qcd background
 - jet combinatorics
 - 6 jets (2 b jets)

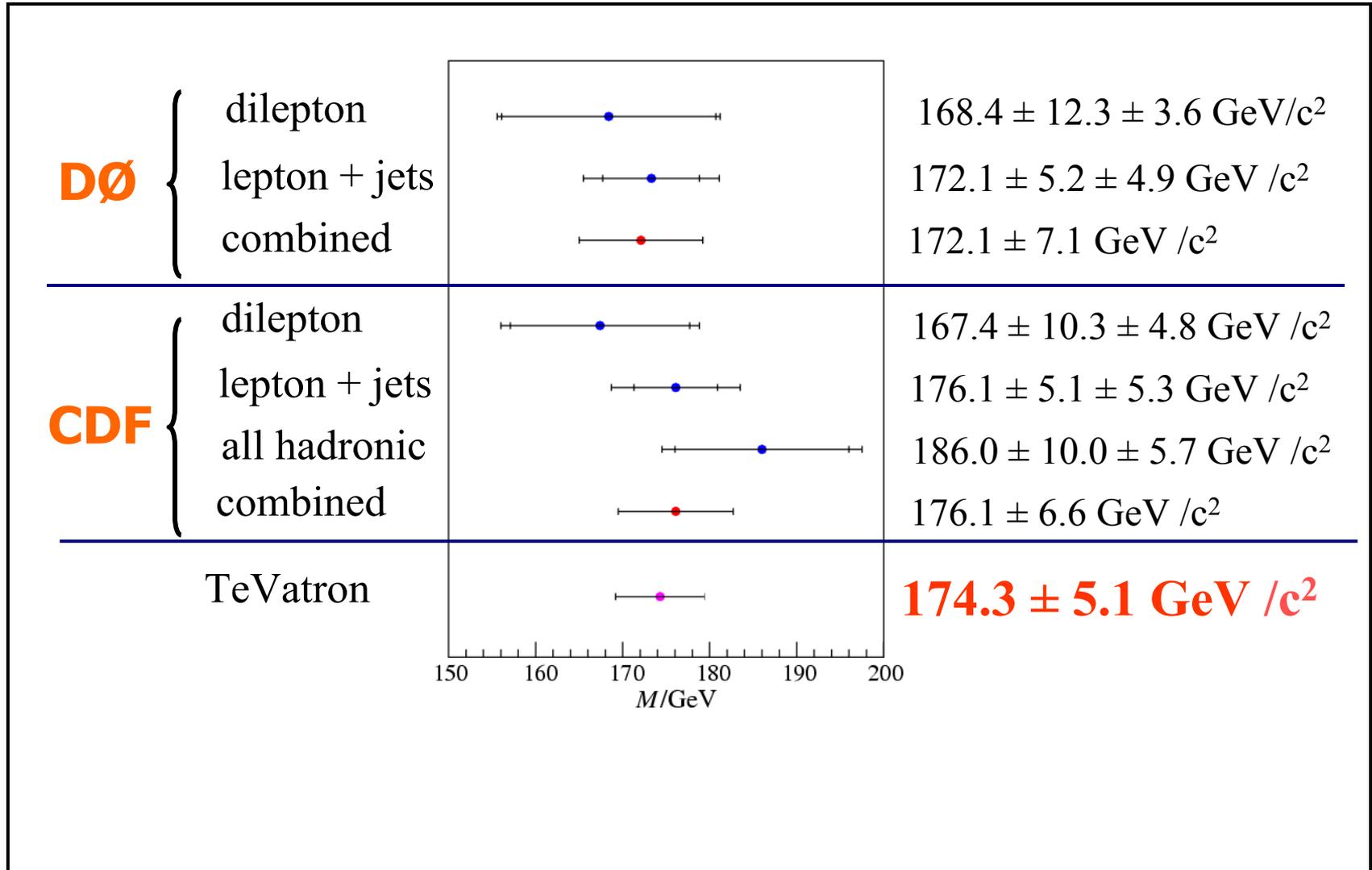
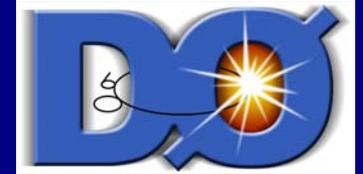


Tagging of b-quarks reduces background and combinatorics:

soft lepton tag ($b \rightarrow l \mu c$)
secondary vertex tag



Run I Results



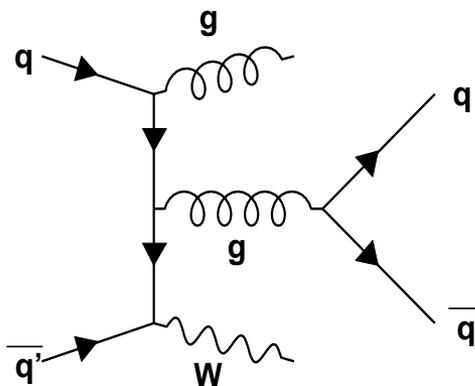
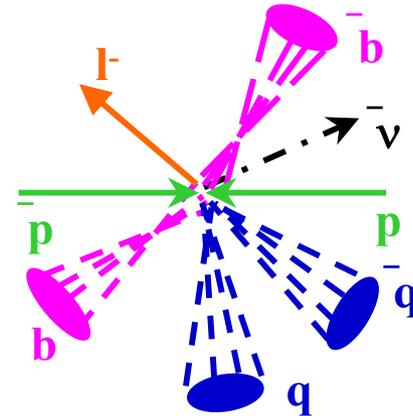
CDF Run II Top Mass Measurement



➤ Event selection (same as Run I)

- ◆ Exactly one isolated high p_T e or μ
- ◆ Missing $E_T > 20$ GeV
- ◆ Jets $E_T > 15$ GeV & $|\eta| < 2$
- ◆ Z and cosmic veto

72 pb⁻¹ 33 candidates



➤ Backgrounds

- ◆ W + jets (*measured from data and MC*)
- ◆ Non W background (fake lepton) (*measured from data*)
- ◆ Diboson, Drell-Yan, single top (*small measured from MC*)

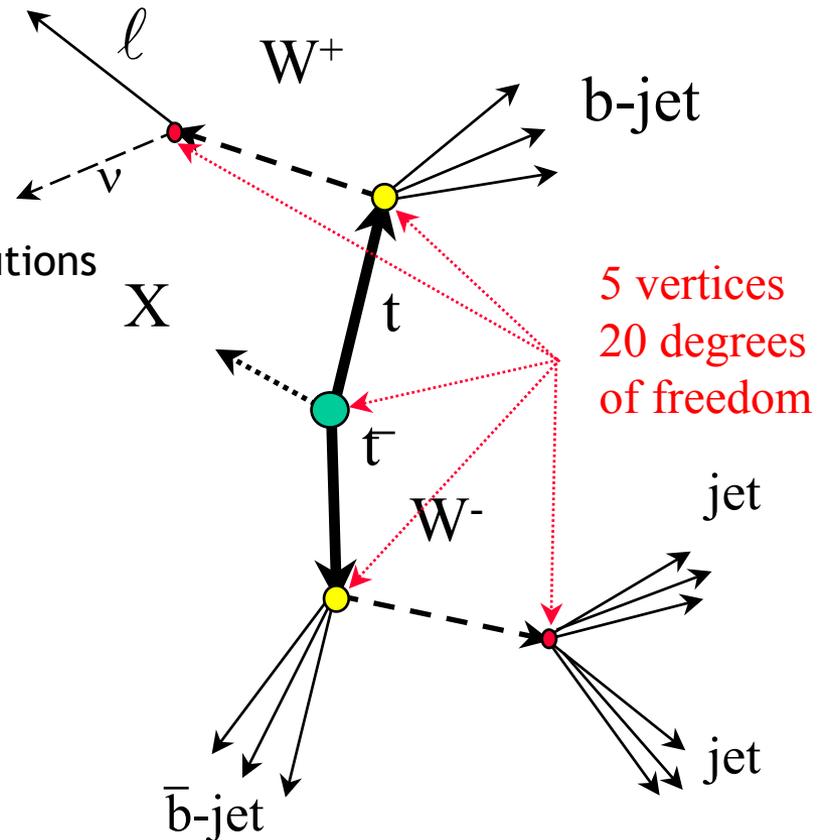


Lepton + jets Kinematics

- ◆ 4 jets => 12 combinations
 - x2 depending on kinematics ambiguities
 - every combination has two solutions for p_z^{ν}

- ◆ 2-constraint kinematical fit $\rightarrow M_{\text{top}}$

- p_{ν} unknown	-3
- Impose p_T balance	+2
- $M(q_1 q_2) = M_W$	+1
- $M(\ell \nu) = M_W$	+1
- $M(W^+ b) = M(W^- b)$	+1





Outline of the Method

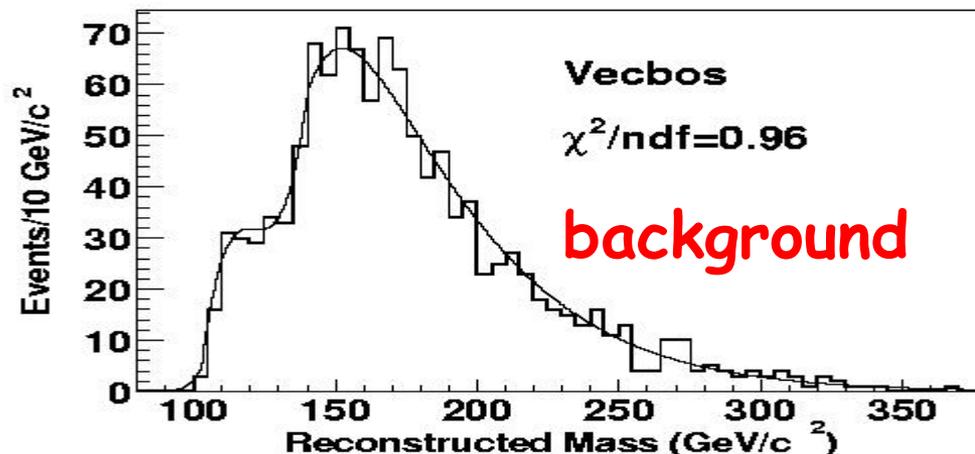
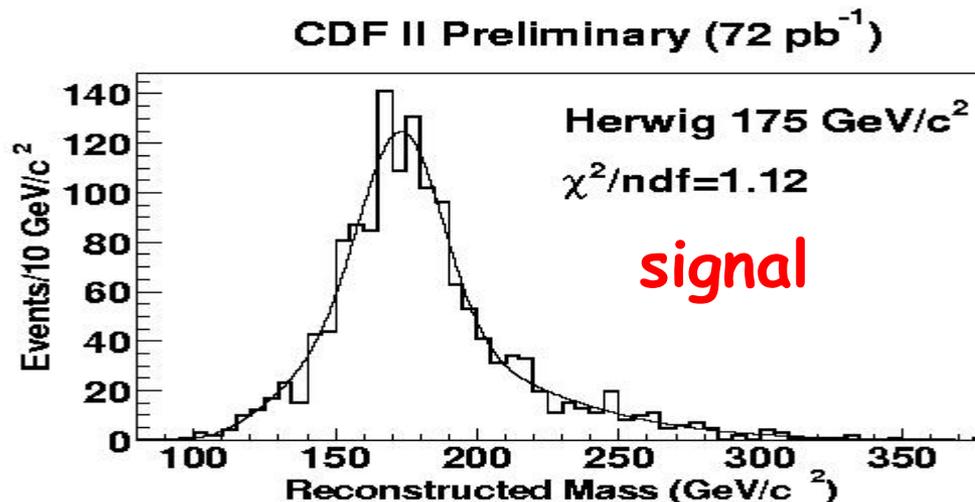
- ◆ 2-constraint fit applied, combination with lowest χ^2 is chosen for top mass

- ◆ Reconstructed top masses from data are compared to *parameterized* templates of top and background Monte Carlo

- ◆ Extract top quark mass and statistical uncertainty using maximum Likelihood

- ◆ M_{top} is the minimum of the log-likelihood distribution

- ◆ σ_{top} corresponds to a change of 0.5 units in the log-likelihood



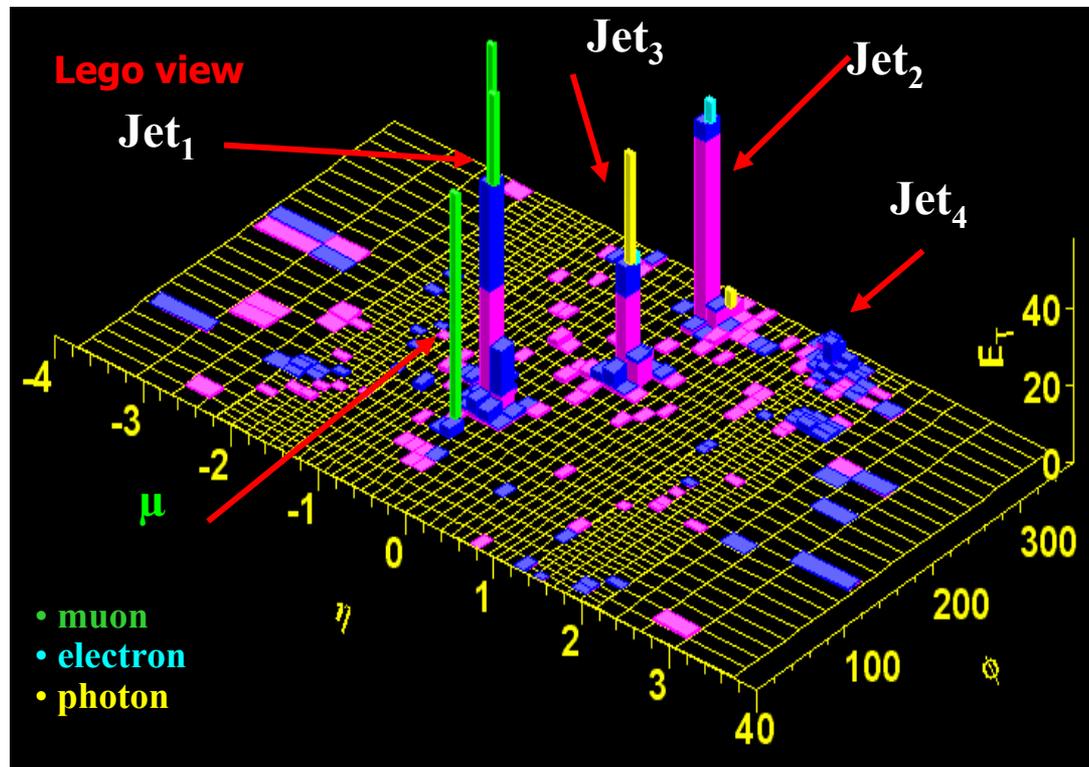


ttbar l+jet candidate

tt l + jet candidate:

Nov 02 2002 run: 153693 event: 799494

μ (CMUP) + 4 jets





Result

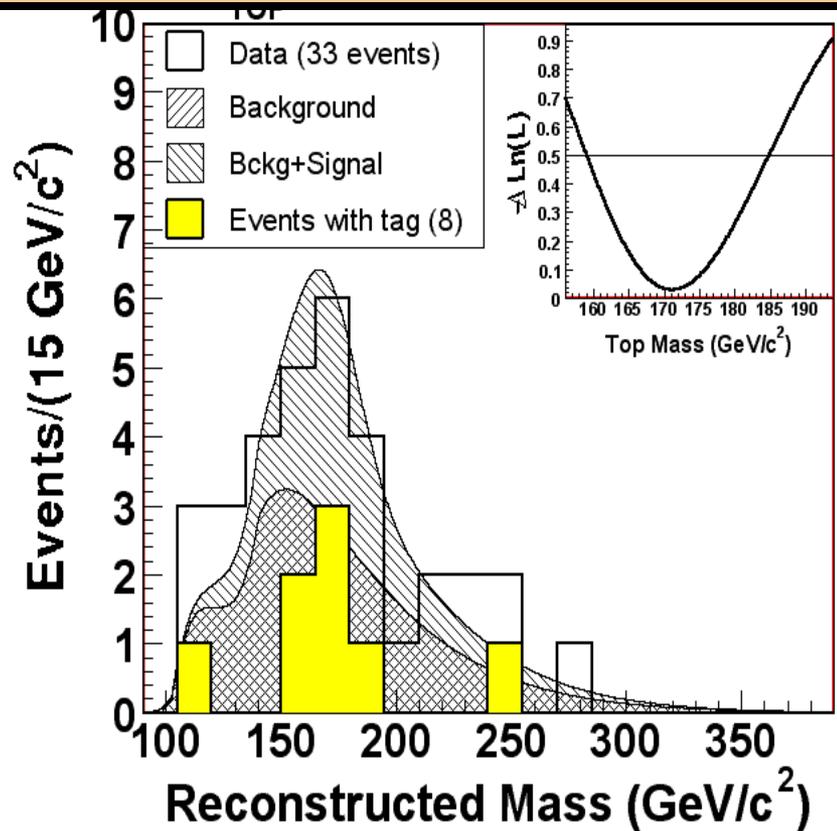
$$M_{\text{top}} = 171.2 \pm 13.4_{\text{stat}} \pm 9.9_{\text{sys}} \text{ GeV}/c^2$$

CDF Run I combined:

$$M_{\text{top}} = 176.1 \pm 6.5 \text{ GeV}/c^2$$

Will improve with
detector understanding
Run I was 4.4 GeV

Source	Uncertainty (GeV/c ²)
Jet Energy Measurement	9.3
Initial and Final State Radiation	2.4
Background Shape	0.3
Parton Distribution Functions	1.8
Monte-Carlo Generators	1.8
Total	9.9





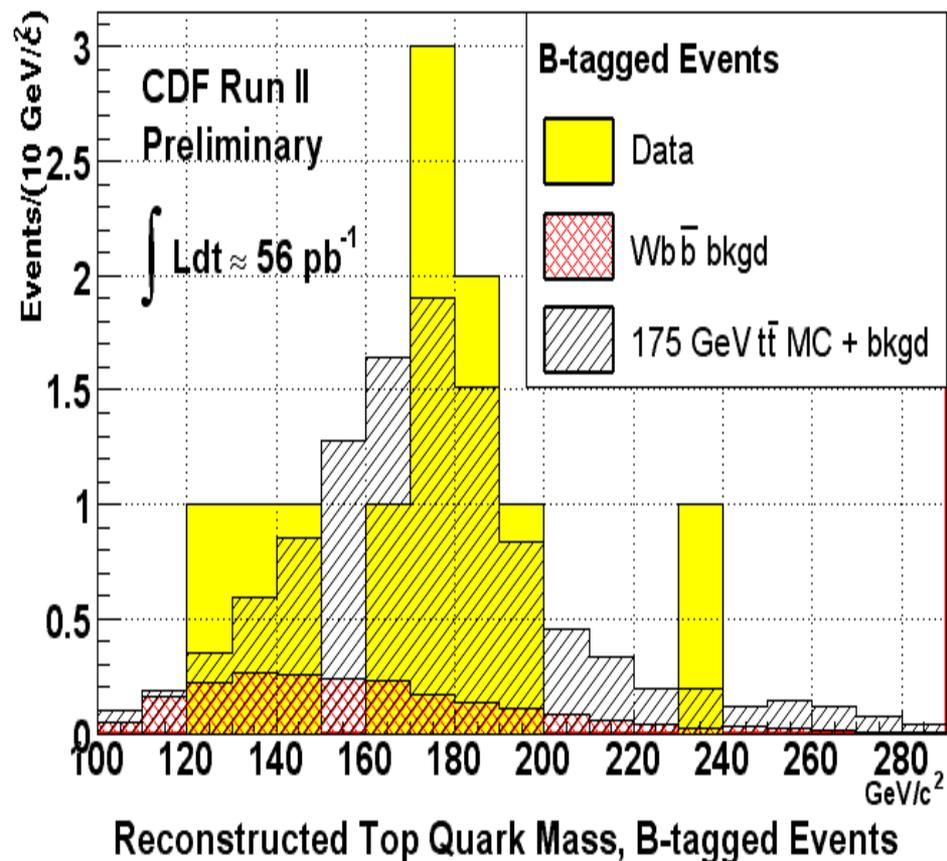
Using b-tagging

Event tagging efficiency $\varepsilon = 45 \pm 1 \pm 5 \%$
(from data + MC)

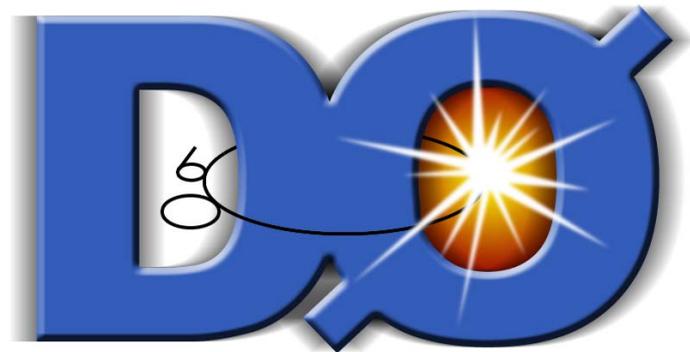
Cleaner sample: smaller
combinatorics, smaller
background

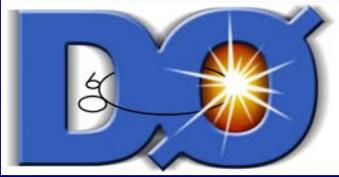
- 3 or more jets
- at least 1 b-tagged jet
- **11 candidates**

Work in progress



DØ Run I Top Mass Measurement





Outline of the method

Likelihood method using most available information

Signal & Background $P_0(x; c_1, c_2, \alpha) = c_1 P_{t\bar{t}}(x; \alpha) + c_2 P_{W+jets}(x)$

Detector Acceptance $P(x; \alpha) = Acc(x) P_0(x; \alpha)$

Likelihood
$$-\ln L(\alpha) = -\sum_{i=1}^N \ln P(x_i; \alpha) + N \int P(x; \alpha) dx$$

$$-\ln L(\alpha) = -\sum_{i=1}^N \ln [c_1 P_{t\bar{t}}(x_i; \alpha) + c_2 P_{W+jets}(x_i)] + N \int A(x) [c_1 P_{t\bar{t}}(x; \alpha) + c_2 P_{W+jets}(x)] dx$$

- ❖ The values of c_1 and c_2 are optimized, and the likelihood is normalized automatically at each value of α



Signal and Background Probabilities

Signal Probability

Measured, reconstructed
objects in the event

to be estimated

resolutions,
reconstruction effects

$$P(x; \alpha) = \frac{1}{\sigma} \int d^n \sigma(y; \alpha) dq_1 dq_2 f(q_1) f(q_2) W(x, y)$$

Matrix Element

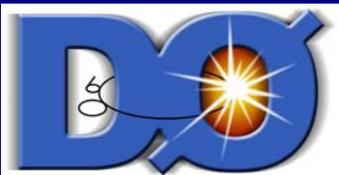
PDF's

where

$$\alpha = M_{top}$$

Background Probability

- ❖ Only in terms of the main background (W+jets, 80%)
- ❖ Calculated using VECBOS subroutines for W+jets



Event Selection

- DØ Statistics Run I (125 pb⁻¹)
 - **Standard Selection:**
 - **Lepton:** $E_T > 20 \text{ GeV}$, $|\eta^e| < 2$, $|\eta^\mu| < 1.7$
 - **Jets:** ≥ 4 , $E_T > 15 \text{ GeV}$, $|\eta| < 2$
 - **Missing $E_T > 20 \text{ GeV}$**
 - **" E_T^W " $> 60 \text{ GeV}$; $|\eta_W| < 2$**

91 events

Ref. PRD 58 (1998), 052001

- **Additional cuts for this analysis :**

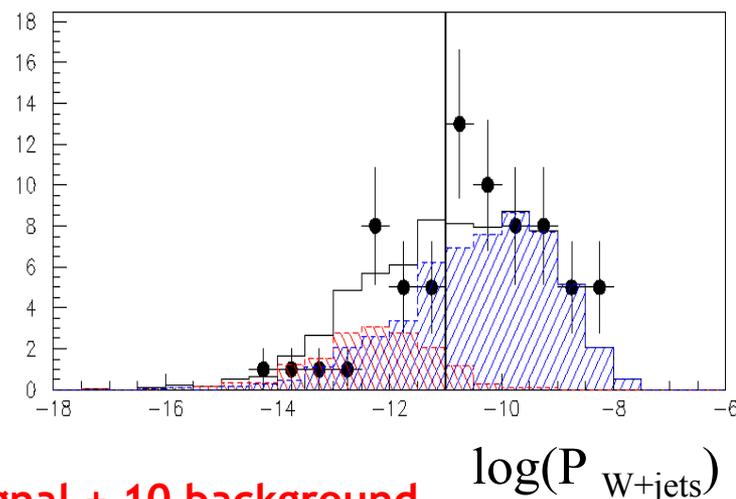
- 4 Jets only -> LO ME is used in probability calculation

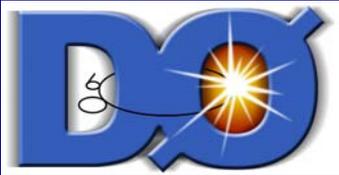
71 events

- Background probability

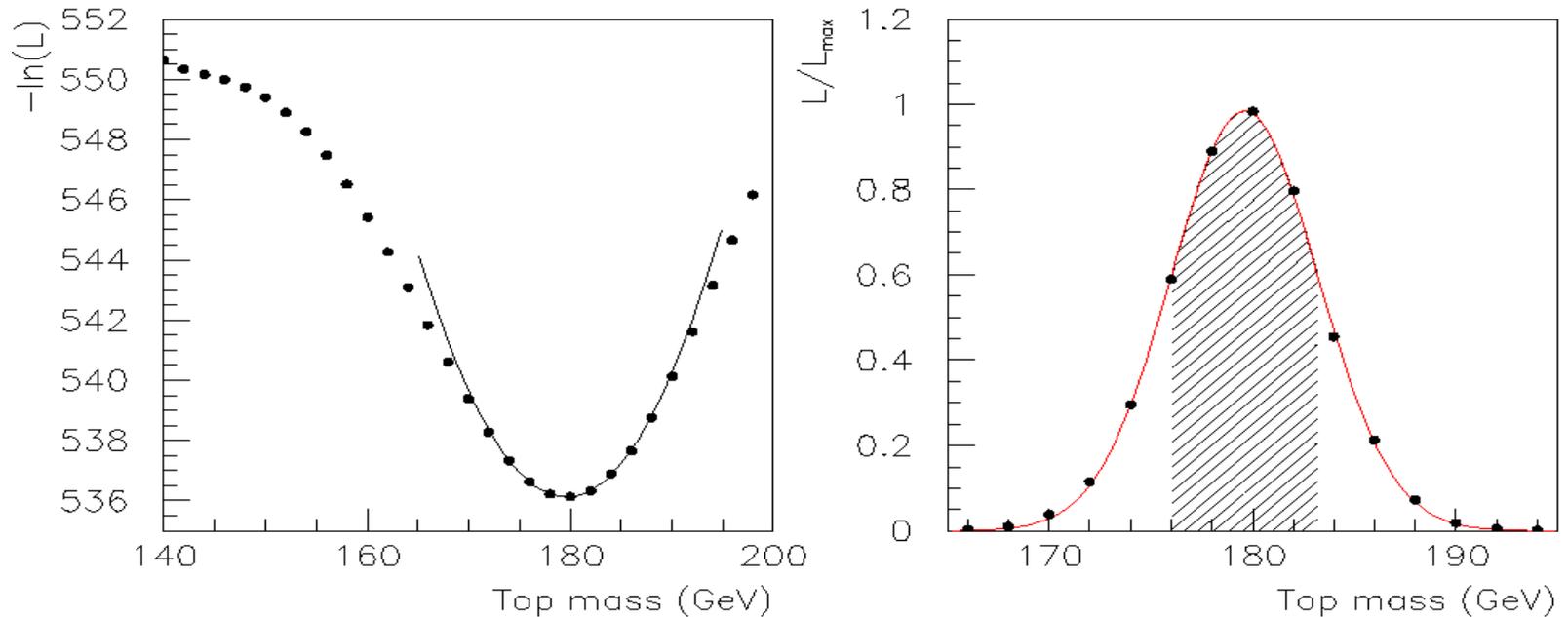
-> to improve purity

22 events => estimated 12 signal + 10 background





Result



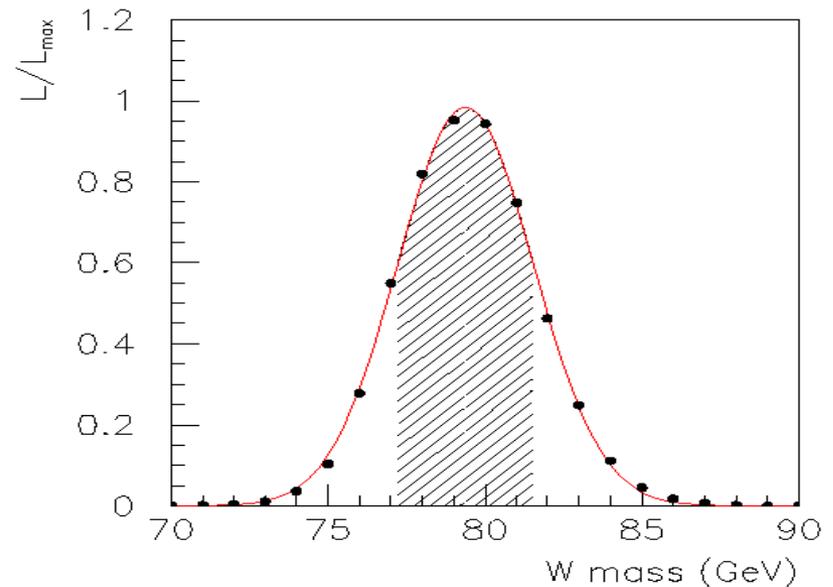
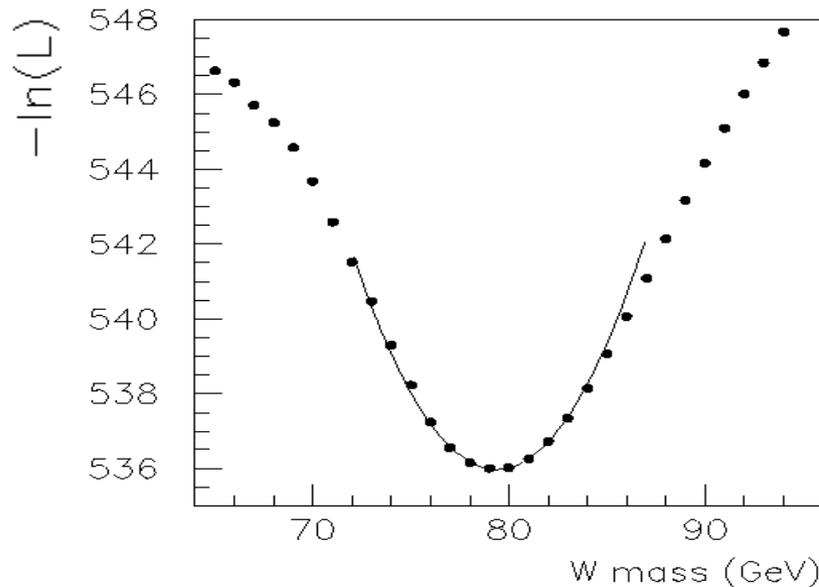
$$M_{\text{top}} = 180.1 \pm 3.6_{\text{stat}} \pm \text{SYS GeV}$$

This new technique improves the statistical error on M_t from 5.6 GeV [PRD 58 52001, (1998)] to 3.6 GeV.

This is equivalent to a factor of 2.4 in the number of events.

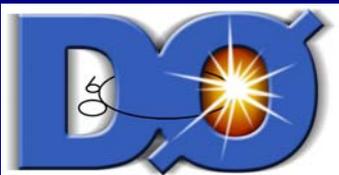


Check of M_W with DØ Run I Data



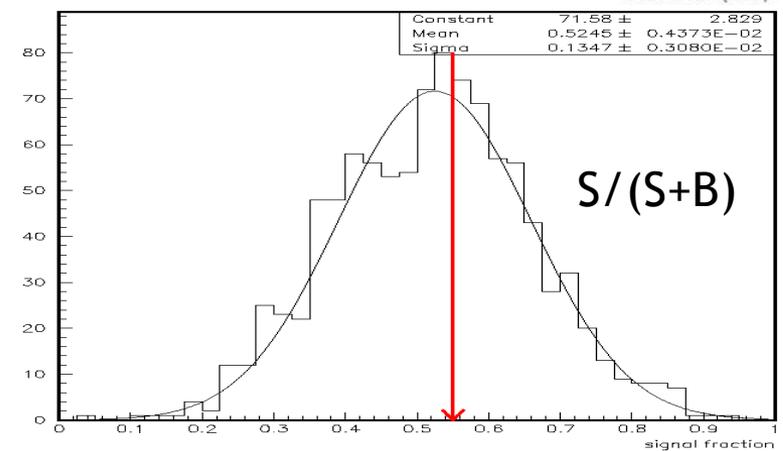
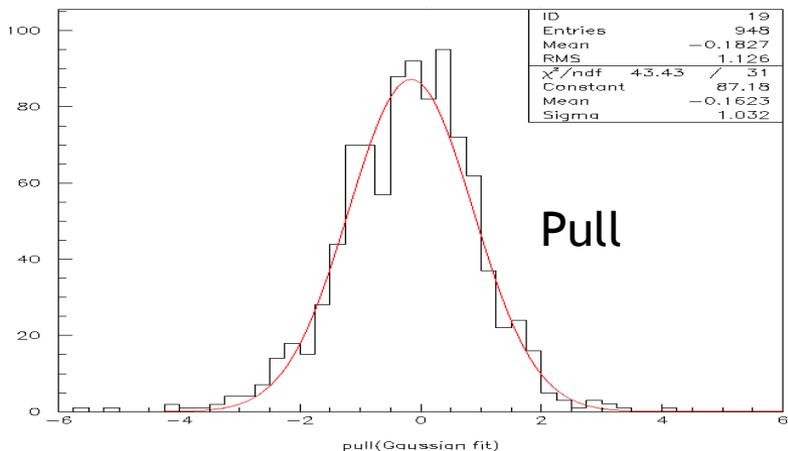
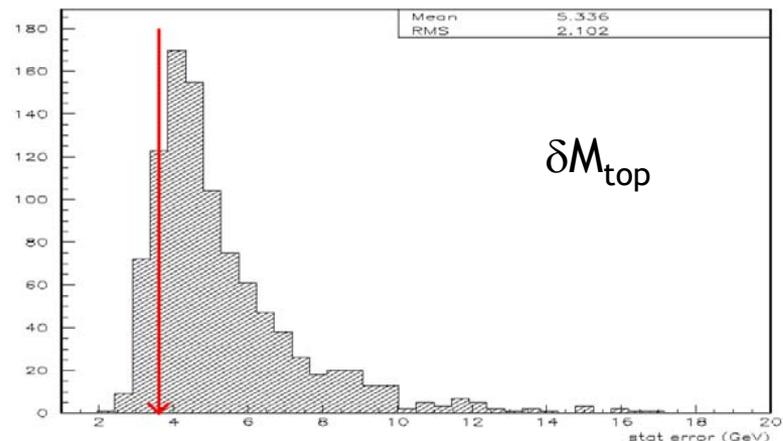
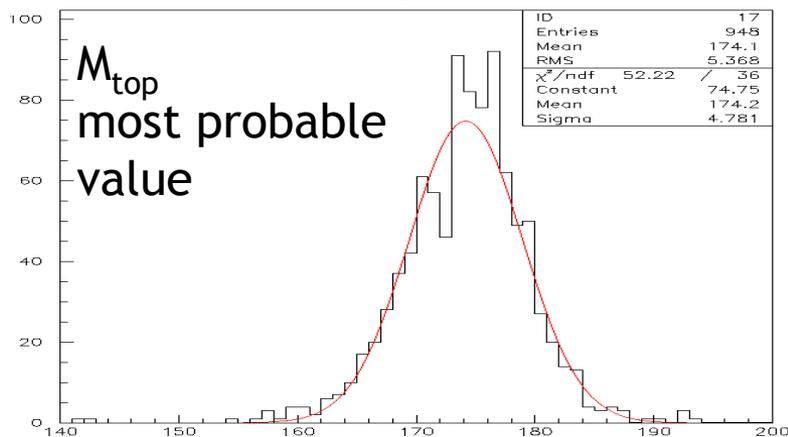
Can help reduce the uncertainty in the jet energy scale (JES)

Expect a substantial improvement in the JES systematic, and the application of this technique to many measurements



Monte Carlo studies with 12s+10b

The MC simulations show that the results obtained are consistent with expectations ($M_{\text{top}} = 175 \text{ GeV}$)





Total Uncertainty

I. Determined from MC studies with large event samples:

Signal model	1.5 GeV
Background model	1.0 GeV
Noise and multiple interactions PRD 58 52001, (1998)	1.3 GeV

II. Determined from data:

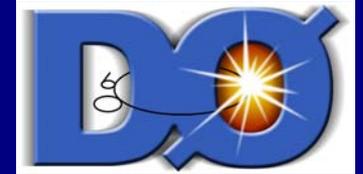
Jet Energy Scale	3.3 GeV
Parton Distribution Function	0.2 GeV
Acceptance Correction	0.5 GeV

Total systematic: 4.0 GeV

$$M_{\text{top}} = 180.1 \pm 5.4 \text{ GeV (preliminary)}$$



Conclusions



TeVatron Top Mass Run I Measurement (CDF, DØ 1999)
(new result not included)

$$M_{\text{top}} = 174.3 \pm 5.1 \text{ GeV}/c^2$$

Improved top mass measurement from Run I (DØ, 2003)

$$M_{\text{top}} = 180.1 \pm 3.6 \text{ (stat)} \pm 4.0 \text{ (sys)} \text{ GeV}/c^2$$

Top Mass from Run II (CDF, 2003)

$$M_{\text{top}} = 171.2 \pm 13.4 \text{ (stat)} \pm 9.9 \text{ (sys)} \text{ GeV}/c^2$$

Improvements for Run IIa:

- Improved b-tagging
- Jet Energy Scale
- Improved Techniques
- Expected ΔM_{top} 2-3 GeV/c²